Evaluation of short-term outcomes of experimental stifle luxation in feral pigeons (Columba livia domestica) treated with a hinged transarticular external skeletal fixator and physical therapy

Azmanis, Panagiotis N ; Voss, Katja ; Hatt, Jean-Michel

Abstract: To evaluate the use of the FESSA hinged linear transarticular external fixator (HLTEF) and the effect of early physical therapy after experimental stifle luxation in pigeons, eight feral pigeons (Columba livia domestica) underwent surgery and afterwards one group started physical therapy on day 1 post surgery, while the other after HLTEF removal on day 21. Healing was evaluated with clinical, radiographic, pathologic, and histologic criteria for 43 days. All birds healed clinically and radiographically. No significant difference was detected between groups in range of motion, thigh thickness and circumference, or muscle/ joint histology. Regressive lameness and pododermatitis affected all birds. Pathology revealed joint capsule fibrosis, hemorrhagic synovial fluid, and callus formation around the pins. Degenerative joint changes were evident histologically. Concluding, this study demonstrated the successful use of the FESSA hinged linear transarticular external fixator for the treatment of stifle luxation and emphasized the difference between clinical and histological healing outcome.

Evaluation of Short-term Outcomes of Experimental Stifle Luxation in Feral Pigeons (*Columba livia domestica*) Treated with a Hinged Transarticular External Skeletal Fixator and Physical Therapy

P. N. Azmanis[a]*

K. Voss[b]

J.-M. Hatt[a]

[a] *Clinic for Zoo Animals, Exotic Pets and Wildlife, Vetsuisse Faculty, University of Zurich, Switzerland*

[b]*University of Veterinary Teaching Hospital, Faculty of Veterinary Science, University of Sydney, 2006, NSW, Australia*

Corresponding author. Current address: Schloßbachstr 43, 77855, Achern, Germany
Phone: 004917637738248
E-mail: azmanis.vet@gmail.com

KEY WORDS: pigeon, stifle luxation, FESSA-HLTEF, physical therapy, histology

ABSTRACT

To evaluate the use of the FESSA hinged linear transarticular external fixator (HLTEF) and the effect of early physical therapy after experimental stifle luxation in pigeons, eight feral pigeons (*Columba livia domestica*) underwent surgery and afterwards one group started physical therapy on day 1 post surgery, while the other after HLTEF removal on day 21. Healing was evaluated with clinical, radiographic, pathologic, and histologic criteria for 43 days. All birds healed clinically and radiographically. No significant difference was detected between groups in range of motion, thigh thickness and circumference, or muscle/joint histology. Regressive lameness and pododermatitis affected all birds. Pathology revealed joint capsule fibrosis, hemorrhagic synovial fluid, and callus formation around the pins. Degenerative joint changes were evident histologically. Concluding, this study demonstrated the successful use of the FESSA hinged linear transarticular external fixator for the treatment of stifle luxation and emphasized the difference between clinical and histological healing outcome.

INTRODUCTION

Stifle luxation (femorotibial joint) has been recorded in poultry (Duff, 1985), psittacine (Holz, 1992; Rosenthal et al., 1994; Donato, 2000; Jaffe et al., 2000; Alievi et al., 2001; Bowles and Zantop, 2002; Harris et al., 2007), raptors (Rosenthal et al., 1994; Naldo and Samour, 2002) or other avian species (Schuster and Krautwald-Junghanns, 1996; Fukui et al., 2005; Chinnadurai et al., 2009). Developmental abnormality (Clipsham, 1991; Bennett, 1998), spontaneous orthopedic disease (Harcourt-Brown, 2000), and traumatic episodes (Bowles and Zantop, 2002; Naldo and Samour, 2002; Fukui et al., 2005) can result in stifle luxation. Stifle luxations typically occur with concomitant damage to ligaments (Duff, 1985; Clipsham, 1991; Fukui et al., 2005), muscles, and nerves (Martin and Ritchie, 1994; Chinnadurai et al., 2009), while menisci are rarely affected (Harcourt-Brown, 2000). Diagnosis is based on clinical signs and confirmed radiologically (Bowles and Zantop, 2002). Various methods, ranging from conservative management to invasive surgical procedures, have been proposed for stifle stabilization in birds (Holz, 1992; Rosenthal et al., 1994; Donato, 2000; Jaffe et al., 2000; Olsen et al., 2000; Alievi et al., 2001; Bowles and Zantop, 2002; Villaverde et al., 2005; Harris et al., 2007; Chinnadurai et al., 2009). Recently, a hinged linear transarticular external fixator (HLTEF) has been proposed for treatment of limb deformities in avian species (Ferraz et al., 2010).

The avian stifle joint anatomy and kinematics are equally complex to the canine and human, and there are anatomic (osseous, soft-tissue, structural) and functional differences among avian and mammalian joint as well as among avian species. Limitations in avian orthopedic surgery have been extensively described (Martin and Ritchie, 1994; Bennett, 1998; Olsen et al., 2000). Avian orthopedic surgery shares the same principles with the mammalian procedure, but differs in that:

- bone cortices are thinner and more brittle (pneumatised bones)
- bone healing is faster
- less soft tissue covers the bones, and
- load bearing must be rapid due to bipedal locomotion.

The size, the weight, the holding strength of the materials as well as the higher anesthetic risk limits the methods that are applicable in the daily routine.

The FESSA (Fixateur Externe du Service de Santé des Armées) external fixator is a commercially available system that has been successfully applied for fracture management in avian patients (Hatt et al., 2007). The various diameter tubes used as connecting bars are strong, light-weight, allow gradual dynamization, and can be assembled to create numerous construct configurations (Type I, II, Tie-in). Hinges can be connected two FESSA tubes, resulting in a FESSA-HLTEF. To the author's knowledge this type has not been evaluated for the management of joint injuries in avian species.

The primary objective of this project was, therefore, to evaluate the use of the FESSA-HLTEF for maintaining postoperative stifle joint stability after lateral collateral ligament replacement in experimentally induced stifle joint luxation in birds. Additionally, the effect of early postoperative physical therapy as compared to late physical therapy was studied. We hypothesized that early physical therapy would result in improved early stifle joint function.

MATERIALS AND METHODS

Animal Model

Eight domestic pigeons (Columba livia domestica), with a mean weight 330 gr, were used in the present study. The birds were determined to be healthy based upon full clinical examination, body radiographs, parasitologic, bacteriologic, haematologic and serologic (for Newcastle disease/ PMV-1) examinations.

An additional two intact, non-operated pigeons were sacrificed prior to the study as controls for the muscle and joint histology. Sex and age was undetermined in all birds. Pigeons were provided from a population control program and the study was approved by the Animal Care and Use Committee of the local authorities.

Experimental Stifle Luxation and LCL Replacement

The birds were premedicated (butorphanol 2mg/kg SC, Torbugesic,), anesthetized with isoflurane, intubated, and placed in left lateral recumbency. The right leg from mid femur to the foot was aseptically prepared. A lateral parapatellar incision was performed. The patella was medially displaced, and the lateral collateral ligament (LCL) and the cruciate ligaments were carefully incised with microscissors. The LCL was replaced with a "figure of eight" suture anchored through the fibular head with the help of 26G needle, used as suture guide trough the tissues, and around a 1.5 mm cortical screw (Cortical bone screw (Ø1.5 mm x 7mm, mixture of chromium-nickel-molybdenum & stainless Steel 1.4441 in DIN 7443, Medical-Solution GmbH, Steinhausen, CH) inserted into the lateral condyle. A 3-0 nylon monofilament suture (Prolene ®Ethicon Inc, Sommerville, NJ, USA) was tied, while the tibiotarsus was held in alignment of the functional 60° angle. The articular cavity was visually inspected, flushed with normal saline, and the capsule was closed, in a simple or cruciate interrupted pattern, with a 4-0 polydioxanone suture (PDS II, Johnson & Johnson Int, c/o European Logistics Centre, St Steven-Woluwe, B). The fascia lata and the skin were closed with a simple interrupted pattern.

Hinged Transarticular External Skeletal Fixator Application

A functional stifle joint angle of approximately 60° was selected for postoperative transarticular immobilization based on literature (Cracraft, 1971; Duff, 1986; Clipsham, 1991; Holz, 1992; Bennett, 1998; Fukui et al., 2005; Villaverde et al., 2005) and goniometry (Knap et al., 2007), while the instant center of rotation (ICR) was calculated, as in dogs, based on the Reuleaux mechanic principles (Reuleaux, 1876). Two 6 mm FESSA connecting bars (6 mm x 31 mm, stainless steel Medical-Solution GmbH, Steinhausen, CH) were linked with a hinge (Veterinary Instrumentation Ltd, Sheffield UK) at the pre-fixed angle (60o) (Fig1). The ICR of the hinge was superimpositioned to the ICR of the joint, near the articular surfaces.

After stab incisions, soft-tissue retraction and bone exposure, two mini ESF pins (IMEX, INTERFACE™ Fixation Half-pins 0035", Ø 0.9 mm, 75 mm, Medical Solution GmbH, Steinhausen, CH) were introduced into the mid-diaphysis and proximal femur in a lateromedial direction, and two additional pins into the mid-diaphysis and the distal tibiotarsus (Fig 2). The distal tibiotarsal pin was angled to 30° to increase stability. The hinge function was tested during flexion-extension. The external skeletal fixation (ESF) was bandaged and sterile sponge was placed around the pins and between fixator and skin.

Postoperative Care

Postoperatively, pigeons were kept in a small pet-porter for 15 hours, and subsequently moved to a box measuring 42 cm x 42 cm x 58 cm for 6 weeks. Implants were inspected daily and diluted povidone iodine solution was applied on each pin tract for 10 days. The bandage was changed every 2 days and removed after 7 days. The physical therapy was combined with the bandage change and inspection. Carprofen (Rimadyl®, Pfizer AG, Zurich, CH 2mg/kg, IM, SID) was administered for 7 days and enrofloxacin (Baytril 5%®, Bayer, Leverkusen, DE, 15 mg/kg, SC, BID) for 5 days.

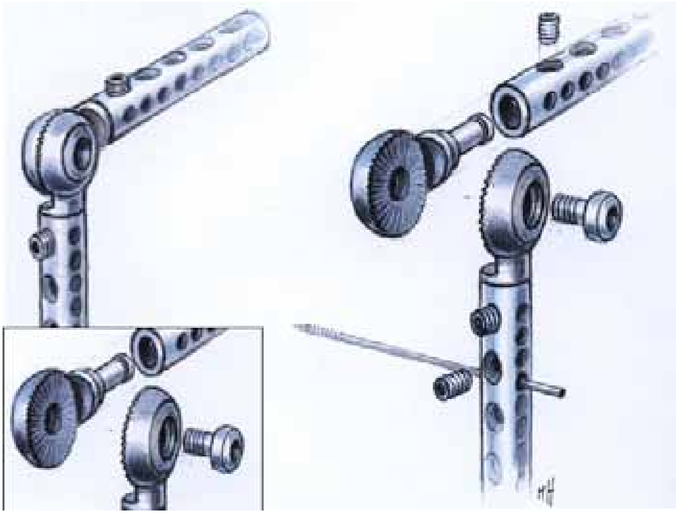
Physical Therapy Protocol

Birds were randomly divided in two groups. The early physical therapy group (EPG) started physical therapy on day 1 post-surgery and for the subsequent 3 weeks. Each bird received 11 sessions of passive physical therapy every other day under isoflurane anesthesia (Table 1). The hinge was completely loosened in the fourth week allowing restricted active motion of the stifle joint in flexion and extension. The late physical therapy group (LPG) had completely immobilized stifle joints for the first 3 weeks post-surgery. On the fourth week, the HLTEF was removed and the pigeons received physical therapy for the following 3 weeks, using the same protocol as applied to the birds in the EPG. Active physical therapy was encouraged throughout the study in both groups by adding an orthopedic "pillow" (diaper stuffed with hay) to produce an uneven level with rugged surface, placed on the floor 24 hours after surgery.

Clinical Evaluations

Clinical evaluation of the birds was per-

Figure 1: *The FESSA hinge and the components of the hinged linear external skeletal fixator (HLTEF). In the magnified pictures, details of the internal part of the hinge and its trailing periphery are shown. The two hemi-parts are fixed together with a hexagonal screw and to the FESSA tubes with a normal pin screw.*



formed daily whilst stifle palpation and external fixator evaluation was performed during every anesthesia session (Harari, 1992; Kraus et al., 2003). Occurrence of pododermatitis was monitored daily with a five-grade scale as previously described (Remple and Al-Ashbal, 1993). Lameness was monitored daily with a numerical rating scale grading from 0 (non lame) to 5 (recumbent). The use of perch was evaluated daily. Thigh muscle circumference (TC), mid-thigh thickness (TTh) and range of motion (ROM) of the femorotibial joint were assessed preoperatively and 3 and 6 weeks postoperatively. ROM was measured during flexion and extension with a goniometer. TC and TTh were measured at the midpoint on the long axis of the femur with a metric tape and a normal ruler, respectively. All values were obtained in triplicate and the mean value was calculated.

Radiographic Evaluation

Orthogonal radiographs of both legs were taken, under isoflurane anesthesia, preoperatively, after surgery, and before euthanasia (day 42). The contralateral stifle was radiographed as a control. The radiographs were evaluated for degenerative changes, implant position, and implant complications.

Euthanasia and Synovial Fluid

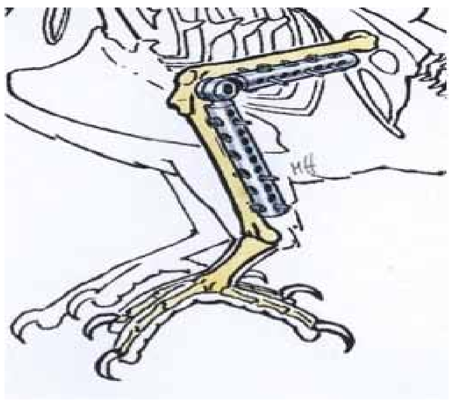
Examination

Six weeks after surgery, all birds were humanely euthanized under general anesthesia with intravenous injection of barbiturates. Before the post-mortem examination of both femorotibial joints, synovial fluid was aseptically collected and cytologically evaluated using modified Wright's stain.

Muscle and Stifle Histology

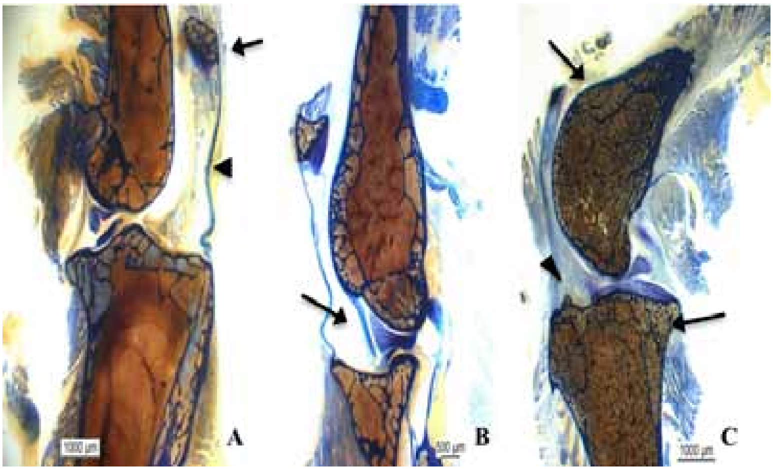
The right and left femorotibial and gastrocnemius muscles of each pigeon were fixed in 4% formalin and submitted for routine histology to detect atrophy, hypertrophy, and morphological changes (haematoxylin-eosin stain). The untreated left leg was used as control. The lesions per muscle, the centralization of nuclei, the perivascular fat tissue, as well as presence of

Figure 2: *Depiction of the transarticular hinged linear external skeletal fixation (FESSA-HLTEF) used for the reposition of the avian femorotibial joint in this study.*



possible inflammation and fibrosis, were recorded using a subjective a scoring system ranging from 0 to 3 for the 6-week management period. Indicative muscle fibre morphometry was performed by selectively measuring the diameter of 20 randomly selected fibres (per muscle and per pigeon) in two pigeons (1 from EPG, 1 from LPG). Additionally, the whole stifle bilaterally was fixed in 4% formalin, and after standard histological dehydration processing, two longitudinal thick slides (from the midline of each condyle) and one thin slide (from midline of intercondylar groove) were stained with tolouidine blue, haematoxylin-eosin, and van Kossa/McNeal. A modified Mankin histology scoring system was adapted to evaluate articular cartilage degradation and remodelling of subchondral/trabecular bones (Mankin et al., 1971). Four areas were examined (central and peripheral part of femoral condyles,and cnemial plateau). The histologic scores were compared between groups and limbs.

Figure 3:
A: Normal bone position. The patella (arrow) and patellar ligament (arrowhead) can be seen (thick section, toluidine blue).
B: Normal position. The cranial cruciate ligament (arrow) is visible (thick section, toluidine blue).
C: Possible luxation with excessive trabeculae (arrows) and osteophytes (arrowhead) (thick section, toluidine blue).



Statistical Methods

Means and standard deviations (±SD) of three independent measurements for ROM, TC, and TTh were calculated. For continuous parameters (weight, ROM and thigh measurements) with normal distribution, according to the Kolmogorov-Smirnov test, the Independent Sample t-Test was used to compare groups. Evaluation of nominal parameters (ESF complications, lameness, pododermatitis, perch use and histology) took place performing the non-parametric Mann Whitney U-test. To compare different parameters from different time points, serial paired t-tests with Dunn-Sidak adjustment for multiple testing were used. To correlate different parameters (weight-pododermatitis, lameness-pododermatitis), Spearman's rank correlation analysis was used. All analyses were performed using SPSS 16.0.1 (SPSS Inc., Chicago, IL, USA). The significance level was set to 0.05.

RESULTS

All surgeries and postoperative treatments were carried out uneventfully. Mean surgery time was 124±22 min. All birds were using the operated leg at the end of the study and the fixator remained functional in all birds. Single pin loosening, hemarthrosis, and mild soft-tissue swelling were observed in one bird each. The ICR of the fixator and the system's mobility for physical therapy was deemed appropriate in all cases. In one case (EPG), the hinge angle was readjusted from 60 to 70 degrees to facilitate easier ambulation and bipedal balance.

Lameness and Pododermatitis Evaluation

Severe lameness (4–5) was detectable in all birds 1 day after surgery, which progressively decreased (2: lame but walking) within 24 days and remained until euthanasia. Mild pododermatitis was developed in all birds at the end of the first week, and until the day of euthanasia all birds had acquired a mild bilateral pododermatitis (grade 1). The untreated left leg was always affected first. All birds could perch by the fourth week using both legs, except one bird (EPG).

Radiographic Evaluation

Radiographic evaluations of the stifle joints in the lateral plane were obscured by the fixator tubes and hinge, therefore, stifle joint appearance and positioning could only be evaluated on dorsoventral radiographs. No signs of loosening of the HLTEF were detected.

Stifle ROM, TC and TTh

There was no statistical difference between groups at any time point regarding ROM, TC, or TTh. After 3 weeks both groups showed similar mean values in flexion and extension. After 6 weeks, the EPG had gained a greater degree of ROM, although not statistically significant (Table 2). The progress from the third to the sixth week was greater in the EPG. The decrease from the normal ROM limits of the species was present in both groups, and the acquired ROM only partially fulfilled the functional criteria of the species (Cracraft, 1971). Both groups presented the same pattern in TC. In the EPG the TTh showed a mean 0.3 cm reduction after 3 weeks and a subsequent increase of 0.1 cm by the sixth week, whilst in LPG an initial mean reduction of 0.5 cm was followed by a 0.1 cm increase by the sixth week. The TTh changes of the left thigh (by day 42) was similar. TC showed no significance between left and right leg; in contrast, the left thigh had a significantly higher TTh than the right in both groups (paired t-test; EPG $p=0.014$, LPG $p=0.006$).

Postmortem Examination

Orthopedic examination prior to euthanasia revealed no positive drawer movement or tibiotarsal rotation. For the EPG, the orthopedic evaluation took place after the HLTEF was removed. Fibrosis of the joint capsule was deemed mild in two birds of the early physiotherapy group, and was severe in the remaining six. Joint fluid of the right stifle joints had a haemorrhagic appearance or contained blood clots in all but one bird (EPG), and cytologically erythrocytes were prevalent in all right stifles (both groups). No inflammatory cells were detected. Fluid from the left stifle appeared normal.

Muscle and Joint Histology

There were no significant differences between the two groups or between left and right leg in muscle histology and muscle fiber morphometry after 6 weeks. Mild degeneration and regeneration with focal to multi-focal fibrosis was detected in both legs, but more evident in the right. Regeneration process (centralisation of nuclei) was evident. In EPG it was comparatively more than evident than in LPG consisted of more than 20 nuclei/field. The right quadriceps presented also more regeneration activity than the left quadriceps. Indicative muscle morphometry although numerically different was insignificant and within normal range. Joint histology revealed one case of certain subluxation (EPG) and five questionable cases (3 in the EPG, 2 in the LPG) (Fig 3C). No trace of amyloid deposits or inflammation was identified, and two suspected cases of fibrosis of the joint were recorded (both in the LPG). Osteophytes were recorded in the right joint in five cases (3 in the LPG, 2 in the EPG). No osteophytes were detected in the left joints. Remodelling of the trabecular bone was absent (less than 5 osteoid locations in both legs of both groups). Evaluation of the articular cartilage between the two groups was insignificant. In all birds, the right central femoral cartilage was significantly more affected than the left ($p= 0.04$) and the central femoral cartilage was significantly more affected than the peripheral femoral cartilage ($p= 0.017$). Generally, the central areas (femur/cnemial plateau) were more affected than the peripheral area (Table 3).

DISCUSSION

From a clincal point of view, the FESSA-HLTEF system was succesfully applied to pigeons with experimentally induced stifle joint luxation. It offered reliable immobilization, allowed selective remobilization the joint, access for soft-tissue care, and angle readjustment to enhance weight-bearing without the need for removal of the ESF (Donato, 2000). In the present study, as well as in two other studies (Ferraz and Ferrigno, 2008; Ferraz et al., 2010), the use of HLTEF was not associated with osteomyelitis due to intramedullary/transfixation pinning as described in a case report (Harris et al., 2007). A potential challenge during physical therapy and remobilization is that the saw-like periphery of the hinge, if not properly unlocked, could block motion of the hinge. The combination of LCL replacement/HLTEF resulted in clinical healing of the luxation, producing a functionally satisfying outcome within 6 weeks. Similar outcomes have been reported with other techniques performed in various bird species (Holz, 1992; Rosenthal et al., 1994; Donato, 2000; Bowles and Zantop, 2002; Fukui et al., 2005; Villaverde et al., 2005; Harris et al., 2007; Chinnadurai et al., 2009; Ferraz et al., 2010), however, these reports mainly are single case reports. A young cockatoo was successfully treated with a HLTEF for bilateral tibiotarsal-tarsometatarsal luxations and after 10 weeks both fixators were removed without any pin or HLTEF complications (Ferraz et al., 2010). Two goslings with non-reducible tarsometatarsal luxations, treated with HLTEF, showed significant functional improvement but with reduction in ROM (Ferraz et al., 2010). Pigeons treated for experimental distal humeral fractures presented adequate flight capacity after the application of an elbow HLTEF for 13 weeks (Ferraz and Ferrigno, 2008).

A preliminary, comparative study of various different stifle luxation techniques in pigeons suggested that all techniques used could pose a viable treatment option, since clinical healing was evident as evaluated by gait and ability to perch (Villaverde et al., 2005). The latter study however did not include a HLTEF group.

In our study ROM decreased (25% mean loss of ROM in extension, 15% mean loss of ROM in flexion) although less than in other case reports (Rosenthal et al., 1994; Bowles and Zantop, 2002). Most avian studies lack proper goniometric measurements. Loss of ROM might induce contralateral foot pododermatitis, complicate degenerative joint disease in the future, which for wild birds might be critical for the post release survival. The HLTEF use in stifle luxation management is controversial. In birds and human the HLTEF use seems beneficial (Chinnadurai et al., 2009; Stannard et al., 2003), while in dogs which underwent repair of multiple experimentally induced ligamentous stifle injuries, a HLTEF did not prove to be beneficial to rigid stabilization (Lauer et al., 2008). Nevertheless the same study comments that in traumatic or recurrent clinical luxations, in which severe soft-tissue damage may exist, the stabilizing effect of a HLTEF could be beneficial and therefore should be further investigated. For any comparison, the differences in biokinematics, load shifting and motion between bipedal and quadriped species have to be considered.

In the present study the effect of early physical therapy with respect to early return to function was assessed. As no specific physical therapy protocol after stifle surgery for birds was found in the literature we developed one based on similar mammalian protocols (Kraus et al., 2003; Monk et al., 2006). In the most avian case reports physical therapy was recommended after 3 weeks of prior stabilization. Therefore, we decided to use the LPG as control group and to compare it to early physical therapy. In goslings treated with HLTEF, postoperative physical therapy (PROM exercises three times/day) had a subjective positive effect in ROM after 1 week. The ROM of the goslings increased clinically after 2 weeks, while the birds started to gait almost normally (Ferraz et al., 2010). After removal of the HLTEF in the third week and short hydrotherapy sessions, the goslings could walk and swim with some difficulty after six weeks (Ferraz et al., 2010).

In our study, an early gain of ROM in the EPG was not evident in three weeks but after six weeks as numerical, non-significant difference. This is in agreement with the findings of Keller et al. (1994) in dogs. Additionally, ROM decrease was evident during the first 3 weeks, but almost normalized after 42 days, as also shown by a similar study in dogs (Lauer et al., 2008). The lack of expected early improvement in ROM in the EPG may be due to the fact that passive ROM exercised were only performed every other day, which may not have been enough to prevent periarticular fibrosis. However, as physical therapy in birds frequently requires general anaesthesia it would be impractical to perform physical therapy more often.

There are no studies in birds in which lameness was scored or objectively evaluated after a stifle luxation and treatment. Lameness grades improved throughout the study period as expected from similar studies in dogs (Keller et al., 1994; Monk et al., 2006), but without significant difference between the two groups. In the current study although all birds still showed lameness they were able to use the affected limb within 6 weeks after surgery. This is consistent with the clinical outcome of three case reports, using HLTEF (Ferraz and Ferrigno, 2008; Ferraz et al., 2010). In the current study, pododermatitis was present until euthanasia in a low grade so the authors assume that it would have been resolved if birds were allowed to live. Additionally, the TC proved unreliable, as the feathers and the abdominal wall have influenced the accuracy, in contrast with TTh, which was accurate due to the easier access of the metric tape on feather-plucked mid thigh. The significant difference between left and right thigh measurement, suggested the expected muscle hypotrophy of the affected limb due to disuse and the possible compensatory hypertrophy of the left limb as the result of increased workload (weight bearing).

Muscle histology revealed damage to the right femorotibial muscle caused possibly by pin insertion and shear/friction forces during mobilization. This damage was evaluated as non-significant for the future limb and muscle function as regeneration of muscle fibres was in progress and the fibrotic areas were isolated. Joint histology suggested high prevalence of possible subluxation, despite clinical stability and radiographic integrity. The higher incidence of possible subluxations in the EPG could indicate that early remobilization had a negative impact to the stability of the joint. These findings emphasized to importance to evaluate the outcome both by clinical and by histological means. Further studies will need to address the question of a negative effect of early physical therapy in the treatment of luxation in birds.

Limitations of the study include that radiographic interpretation of stifle position on lateral radiographs was not possible due to superimposition of the hinge over the stifle joint. Radiography proved insensitive to detect osteophytes or minimal bone changes due to the small sized articular cavities and the superimposition with the hinge. Although histopathology findings suggested the presence of possible subluxation in a number of joints, this could not be confirmed radiographically. As only sections of the stifle joint are seen on histopathology it was difficult to conclusively rule in or rule out stifle joint subluxation. Another drawback of the study is that the external fixator was left on (albeit with a loosened hinge) in the EPG for the duration of the study, whereas it was removed after 3 weeks in the LPG, which to some degree prevented direct comparison between groups. This was done because of the fear that early physical therapy would have delayed periarticular fibrosis and that these stifles would have had an increased risk for relaxation if the fixator had been removed after 3 weeks. The fact that two birds in the EPG showed minimal fibrosis of the joint capsule may substantiate this concern.

In conclusion, this study demonstrated the successful use of the FESSA-HLTEF for the treatment of stifle luxation, but also emphasizes the differences between clinical and histological healing. The FESSA-HLTEF is an affordable modality for immobilizing and remobilizing the avian femorotibial joint, providing rigidity, gradual dynamization and correction of joint angle. Future studies could further investigate the effect of early physical therapy in avian species, with special emphasis on long-term outcome of clinical traumatic luxations and microscopic intraarticular impact.

ACKNOWLEDGEMENTS

The authors would like to thank Prof. Dr. Marcus Clauss (Clinic for Zoo Animals Exotic Pets and Wildlife, Vetsuisse Faculty, University of Zurich) for reviewing the manuscript and his help with the statistical analysis. We are also grateful for the support regarding the histological joint evaluation offered by Prof. Dr. Brigitte von Rechenberg (Musculosceletal Research Unit, Department of Horses, Vetsuisse Faculty, University of Zurich). Dr. Monika Hilbe (Institute of Veterinary Pathology, Vetsuisse Faculty, University of Zurich) kindly evaluated the muscle histology and morphometry. The illustrations of figures 1 and 2 were produced by Mathias Haab (Department of Horses, Vetsuisse Faculty, University of Zurich).

REFERENCES

1. Alievi, M.M., Hippler, R.A., Giacomelli, L., Guimarães, L., Schossler, J.E., 2001. External Skeletal Fixation for arthrodesis of the knee joint in a parrot (Amazona aestiva). *Ciencia Rural* 31, 1069–1072.
2. Bennett, R.A., 1998. Management of Joint Luxations in Birds, in: REYNOLDS, M.D. (Ed.), "From Science to Reality: A Bridge to the 21st Century". International Wildlife Rehabilitation Council (IWRC) , Concorde, California, pp. 11–15.
3. Bowles, H.L., Zantop, D.W., 2002. A novel surgical technique for luxation repair of the femorotibial joint in a monk parakeet (Myiopsitta monachus). *Journal of Avian Medicine and Surgery* 16, 34–38.
4. Chinnadurai, S.K., Spodnick, G., Degernes, L., DeVoe, R.S., Marcellin-Little, D.J., 2009. Use of an extracapsular stabilization technique to repair cruciate ligament ruptures in two avian species. *Journal of Avian Medicine and Surgery* 23, 307–13.
5. Clipsham, R., 1991. Correction of pediatric leg disorders. In: *Annual Conference of Association of Avian Veterinarians*. pp. 200–204.
6. Cracraft, J., 1971. The functional morphology of the hind limb of the domestic pigeon, Columba livia. Bulletin of the American Museum of Natural History 144, 171–268.
7. Donato, N.L., 2000. Stifle arthrodesis in a military Macaw. Utilising safe,hazardous and danger zones. In: *Veterinarians, A. of A*. (Ed.), Annual Conference of the Association of Avian Veterinarians. pp. 121–126.
8. Duff, S.R.I., 1985. Cruciate ligament rupture in young adult broiler knee joints. *Journal of Comparative Pathology* 95, 537–547.
9. Duff, S.R.I., 1986. Further studies on cruciate and collateral knee ligaments in adult broiler fowls. *Avian Pathology* 15, 407–420.
10. Ferraz, V., Ferrigno, C., 2008. Avaliação radiográfica e de função de vôo após fixação de osteotomias distais do úmero em pombas (Columba livia), com modelo de fixador externo articulado. *Pesquisa Veterinária Brasileira* 28, 351–357.
11. Ferraz, V., Ferrigno, C., Isaza, R., Pozzi, A., Myers, D., Atkins, A., Wellehan, J.F.X., Ito, K., 2010. Treatment of tarsal joint deformities with hinged transarticular external fixators in three young birds. Veterinary and Comparative Orthopaedics and Traumatology : V.C.O.T 23, 362–5.
12. Fukui, D., Bando, G., Kosuge, M., 2005. Stifle luxation repair by articular stabilization technique with non-absorbable suture in a white-fronted goose and therapeutical trial in a domestic pigeon. *Japanese Journal of Zoo and Wildlife Medicine* 10, 49–52.
13. Harari, J., 1992. Complications of external skeletal fixation. *Veterinary Clinics of North America : Small Animal Practise* 22, 99–107.
14. Harcourt-Brown, H.N., 2000. Anatomy of the pelvic limb. In: Harcourt-Brown, H.N. (Ed.), *Birds of Prey*: Anatomy,Radiology, and Clinical Conditions of the Pelvic Limb. Zoological Education Network, Lake Worth, FL, pp. 24–134.
15. Harris, M.C., Diaz-Figueroa, O., Lauer, S.K., Burkert, B., Tully, T.N., 2007. Complications associated with conjoined intreamedullary pin placement for a femorotibial joint luxation in a Solomon Island Eclectus Parrot (Eclectus roratus solomonensis) *Journal of Avian Medicine and Surgery* 21, 299–306.
16. Hatt, J.-M., Christen, C., Sandmeier, P., 2007. Clinical application of an external fixator in the repair of bone fractures in 28 birds. *Veterinary Record* 160, 188–194.
17. Holz, P., 1992. Luxation of the stifle joint in a Major Mitchell cockatoo. *Veterinary Record* 130, 34.
18. Jaffe, M.H., Fitch, R., Rich, G., Tully, T.N., 2000. Medial release and extracapsular stabilization in a 7-month old blue and gold macaw (Ara ararauna) with a grade IV medial patella luxation. In: V*eterinarians, A. of A*. (Ed.), Conference of Association of Avian Veterinarians. pp. 101–104.
19. Keller, W.G., Aron, D.N., Rowland, N.G., Odend'hal, S., Brown, C., 1994. The effect of

trans-stifle external skeletal fixation and hyaluronic acid therapy on articular cartilage in the dog. *Veterinary Surgery* 23, 119–128.

20. Knap, K., Johnson, L.A., Schulz, K., 2007. Fundamentals of Physical Rehabilitation. In: Fossum, T.W. (Ed.), *Small Animal Surgery.* Mosby Elsevier, St. Louis, Missuri, USA, p. 111.
21. Kraus, H.K., Toombs, P.J., Ness, G.M., 2003. External fixation in small animal practice. Blackwell Science Ltd, Oxford.
22. Lauer, S.K., Hosgood, G., Ramirez, S., Lopez, M., 2008. In vivo comparison of two hinged trans-articular external skeletal fixators for multiple ligamentous injuries of the canine stifle. *Veterinary and Comparative Orthopaedics and Traumatology* 1,25–35.
23. Mankin, J.H., Dorfman, H., Lippiello, L., Zarins, A., 1971. Biochemical and metabolic abnormalities in articular cartilage from osteo-arthritic human hips: II. Correlation of Morphology with Biochemical and Metabolic data. *Journal of Bone and Joint Surgery* 53, 523–537.
24. Martin, D., Ritchie, W., 1994. Orthopedic surgical techniques. In: Ritchie, W.R., Harrison, J.G. (Eds.), *Avian Medicine: Principles and Application*. Wingers Publishing INC, Lake Worth, Florida, USA, pp. 1139–1169.
25. Monk, L.M., Preston, A.C., McGowan, L.C., 2006. Effects of early intensive postoperative physiotherapy on limb function after tibial plateau leveling osteotomy in dog with deficiency of the cranial cruciate ligament. *American Journal of Veterinary Research* 67, 529–536.
26. Naldo, L.J., Samour, H.J., 2002. Selected orthopedic cases in falcons in Saudi Arabia. *Exotic DVM* 4.4, 11–13.
27. Olsen, G.H., Redig, P.T., Orosz, S.E., 2000. Limb dysfunction, in: Olsen, G.H., Orosz, S.E. (Eds.), *Manual of Avian Medicine*. Mosby, MO, St. Louis, p. 524.
28. Remple, J.D., Al-Ashbal, A.A., 1993. Raptor Bumblefoot: another look at histopathology and pathogenesis. In: Redig, P.T., Cooper, J.E., Remple, J.D., Hunter, D.B. (Eds.), *Raptor Biomedicine*. University of Minnesota Press, Minneapolis, UK.
29. Reuleaux, F., 1876. The Kinematics of Machinery: Outlines of a Theory of Machines. MacMillan, London.
30. Rosenthal, K., Hillyer, E., Mathiessen, D., 1994. Stifle luxation repair in a moluccan cockatoo and a barn owl. *Journal of the Association of Avian Veterinarians* 8, 173–178.
31. Saunders Gross, D., Walker, J.R., Levine, D., 2005. Joint mobilization. In: Levine, D., Millis, L.D., Marcellin-Little, J.D., Taylor, A.R. (Eds.), *The Veterinary Clinics of North America:Small Animal Practice.* Elsevier Inc, Philadelphia, USA, pp. 1287–1315.
32. Schuster, S., Krautwald-Junghanns, M.-E., 1996. Untersuchungen zu Häufigkeit, *Lokalisation und Art von Frakturen beim Vogel*. Institut für Geflügelkrankheiten. Justus-Liebig Universität, Giessen.
33. Stannard, J., Sheils, T., McGwin, G., Volgas, D., Alonso, E., 2003. Use of a hinged external knee fixator after surgery for knee dislocation. *Arthroscopy* 626–631.
34. Villaverde, S., de la Vibora, B.J., Gonzalez, R., Freire, M., Penà Lopez, M., Guzon Munòz, F., Quiros-Rodriguez, J., 2005. Management of the femorotibial luxation by coaptation splinting, intramedullary pins, external skeletal fixtor and tension bands: a pilot study in domestic pigeons (Columba livia domestica). In: *Veterinarians, E.A. of A*. (Ed.), 8th European Association of Avian Veterinarians / 6th Scientific ECAMS Meeting Arles, France, pp. 196–202.